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CIRCULARLY POLARIZED BROADBAND ANTENNA WITH CIRCULAR SLOT ON CIRCULAR GROUND-PLANE

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Abstract—A novel circularly polarized antenna with a circular radiating aperture and circular ground plane for broadband characteristics is presented in this paper. The vertical and horizontal components of the L-shaped probe are separated and placed at the front and back sides of the substrate. The antenna is excited by a microstrip line which is connected to the vertical component of the L-shaped probe and electromagnetically couples the signal to the horizontal component of the L-shaped probe. The concept of placing an appropriate stub in the slot, by observing the electric field vector behaviour in the slot, is proposed to enhance the axial ratio (AR) bandwidth by around 15%. The fabricated antenna shows wideband impedance and circular polarization characteristics of 48% along with a maximum gain of 6 dBic. The measured and simulated antenna characteristics are in good agreement.

1. INTRODUCTION

Circularly polarized (CP) antennas have advantages over linearly polarized antennas because the electric field alignment between the transmitter and receiver locations is not required [1]. Phasing issues and multi-path fading adversely affect the signal quality when linearly polarized antennas are used [1–4]. Circularly polarized patch antennas, that received large attention initially, have inherently narrow bandwidth [5]. A printed slot antenna design is a desirable solution if the antenna bandwidth has to be improved without increasing the antenna size and thickness [5–7]. Broadband antennas are required for Wireless Local Area Networks (WLAN), Wireless Personal Area Networks (WPAN) and pulse RADAR systems [1, 4], because of various

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applications at different frequencies inbuilt in the same system. Instead of having multiple antennas, a single broadband antenna that covers the entire frequency band could serve the same purpose, which can reduce the system complexity and can be applied to the cognitive radios using tunable filters and switching circuits. Furthermore, broadband CP antennas may also be applied to the chipless RFID systems [8] to avoid the effect of multipath fading. This technique contributes to low cost sensor networks. Slot antennas also provide bidirectional radiation along with greater manufacturing tolerances compared to microstrip patch antennas and well suit for applications that require both left hand circular polarization (LHCP) and right hand circular polarization (RHCP) for transmission and reception. Since the polarization sense changes from RHCP to LHCP and vice versa when reflected, an antenna which could receive both senses is significant, when the antenna needs to receive the reflected signal if the direct signal is obstructed. For applications with switchable RHCP and LHCP, an unavoidable mute occurs because a new synchronization to the digital data stream is needed after switching from one beam to the other. An antenna which receives both CP senses can avoid this problem and is used, for example, in satellite digital radio systems [18] and for the reception of terrestrial signals and signals of geostationary satellites [19].

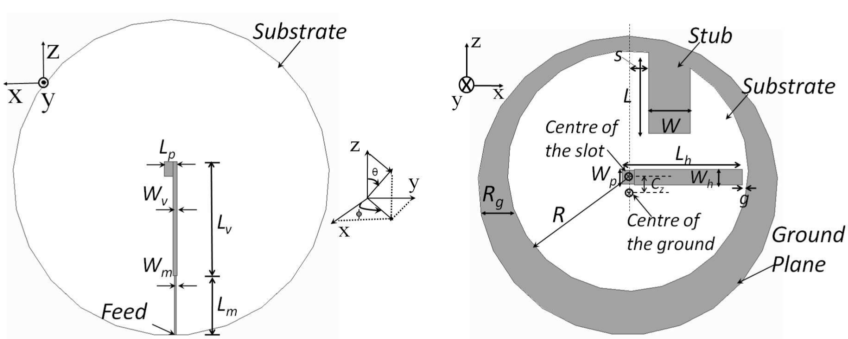
Circularly polarized broadband antennas should provide broadband characteristics in input impedance, axial ratio (AR) and gain characteristics. Slot antennas with large radiating aperture provide wider bandwidth without increasing the size and thickness. This paper is focused on the generation of circular polarization with slot antenna with large aperture using an L-shaped feed probe. The shape of aperture can be modified by studying the behaviour of electric field vectors through recent electromagnetic simulations. By controlling the behaviour with some metallic stub in the slot, broadband characteristics in AR can be obtained. Compared to the single slot planar structures proposed in [13, 14], this antenna requires lesser area by $2500\,\mathrm{mm}^2$. The proposed antenna has an enhanced CP bandwidth of 48%, which is around 7% and 5% more than that in [13, 14]. Also, the antenna has an improved gain of 6 dBic with a cross polarization discrimination of more than 15 dB on a wide azimuth range, which makes the antenna benefitial for applications in short range wireless telecommunication.

2. ANTENNA STRUCTURE

The structure of the proposed circular slot antenna with circular ground plane and rectangular stub in the slot is shown in Figure 1.

The antenna uses a 0.8-mm thick Arlon diclad 522 substrate with a permittivity (ϵ_r) of 2.5 and dielectric loss ($\tan\delta$) of 0.001. The centre frequency (f_0) of operation is decided at of 3.5 GHz. This frequency is selected, so that the antenna can be applied to 3.5 GHz WiMAX [4], chip-less RFID reader systems that make use of lower UWB technique [8] and pulse RADARs. The circular slot made at the centre of the circular ground plane has a radius (R) of 29 mm and designed to be around $\lambda_0/3$ of the centre frequency. The horizontal and vertical components of the L-shaped probe are separated and placed at the front and back sides of the substrate. CP is generated when the two orthogonal linear components of E_θ and E_ϕ are 90° out of phase and have the same amplitude. The vertical (Lv) and horizontal (Lh) components of the L-shaped probe respectively generate the E_θ and E_ϕ constituents of the CP. The horizontal probe has a length (L_h) of 29 mm, which is designed at $0.34\,\lambda_0$. The vertical component of the L-shaped probe that succeeds the microstrip feed line, designed at around $\lambda_0/4$ of the centre frequency, is optimised to 26 mm long (Lv) and 1 mm wide (Wv). The phase condition 'dependence' of CP prominently depends on this parameter [15]. The vertical probe is extended to the edge of the substrate through a matching inductive microstrip feed line of 118 Ω with a width (W_m) of 0.4 mm and length (L_m) of 13.5 mm to match the impedance of the 50 Ω coaxial cable.

The structure is influenced by the circular slot antenna presented in [13], and the main modifications are the shape of the substrate, ground plane and the shift of the slot by C_z in Figure 1. As the antenna size and ground plane size affect the antenna characteristics, the antenna has to be intensely studied and optimized through parametric



(a) Front View (b) Back View

Figure 1. Antenna with circular slot and stub.

studies. The oval stub and the other parameters are kept unchanged initially as in [13], except the size of the ground plane and substrate. The oval shaped stub is placed in the slot to eliminate counter clockwise electric field rotations in the slot, because the antenna can attain wideband CP if the slot has only clockwise rotations. Even if only the ground shape is changed to circle, additional studies are required as the antenna characteristics greatly depend on the size of the antenna. When the antenna shape changes, the electric field and surface current behaviours change, because of which the antenna needs to be analysed further.

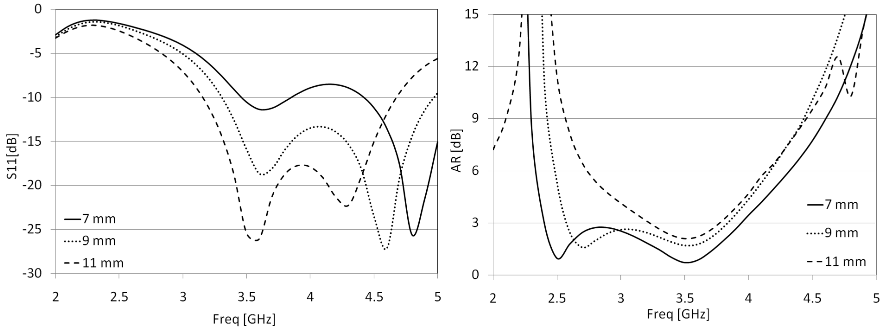
3. PARAMETRIC STUDIES AND OPTIMIZATION OF THE ANTENNA

The antenna analysis and parametric studies are performed using Ansoft HFSS 10.1 based on finite element method (FEM). The parameters that remarkably affect the antenna's behaviour are the size of the ground plane and placement of the slot on the ground plane. The width of the ground plane (R_g) is optimized to obtain wideband CP characteristics, and the position of the slot is shifted in the $+z$ axis (C_z) to achieve broadband impedance characteristics. These two parameters are studied in detail and explained below.

3.1. Optimization of Width of the Ground Plane (R_g)

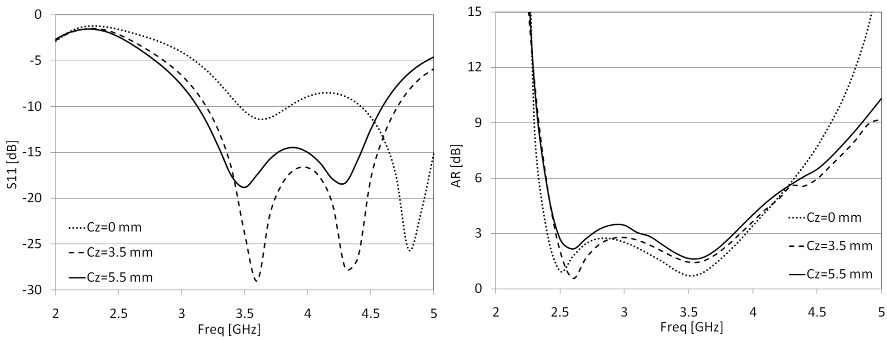
The circular slot of the antenna is made at the centre of the structure initially. The width of the ground plane R_g along with the substrate underneath is varied, and the effects of which on the S_{11} and AR characteristics are shown in Figure 2.

The width R_g of the ground plane is varied from 7 mm to 11 mm. The antenna attains broadband S_{11} characteristics but is unable to obtain the same in AR at $R_g = 11\,\text{mm}$. The E_ϕ value is much stronger than the E_θ, because of which the amplitude ratio is well below 0 dB. At the same time, at 11 mm, the antenna is unable to maintain the 90° of phase difference on a wideband. But as R_g is reduced, the L-probe (the L-probe parameters are not changed) is shifted in the $+z$ axis, which makes the E_θ value stronger, and wideband AR characteristics are obtained at 7 mm and 9 mm. But this shift in the L-probe makes the microstrip feed line exposed to the region of the slot and the antenna more capacitive. Because of this reason, the S_{11} characteristics deteriorate, and the antenna resonates at a higher frequency when R_g is reduced.



(a) S_{11} Characteristics (b) AR Characteristics (+y direction)

Figure 2. Effect of varying the width of the ground plane R_g.



(a) S_{11} Characteristics (b) AR Characteristics (+y direction)

Figure 3. Effect of shift of the slot C_z.

3.2. Effect of Shifting the Slot in $+z$ Axis (C_z)

As the antenna has broadband AR characteristics at 7 mm, in order to obtain broadband impedance characteristics, the inductance in the antenna needs to be enhanced. For that, the slot is shifted in the $+z$ axis, which makes the ground plane narrower at the top region of the antenna. But at the bottom region of the antenna, this shift makes the microstrip feed line covered by the ground plane and the antenna more inductive. A shift by $C_z = 3.5$ mm can provide wideband S_{11} characteristics, but the AR is slightly narrowed down compared to $C_z = 0$ mm, because E_θ value reduces when the slot is at the centre. The effects of C_z on S_{11} and AR characteristics are shown in Figure 3.

The electric field behaviour in the slot of the antenna is studied to

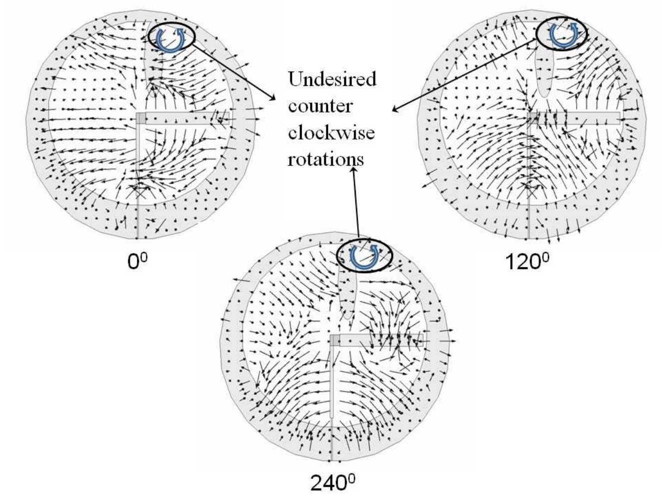
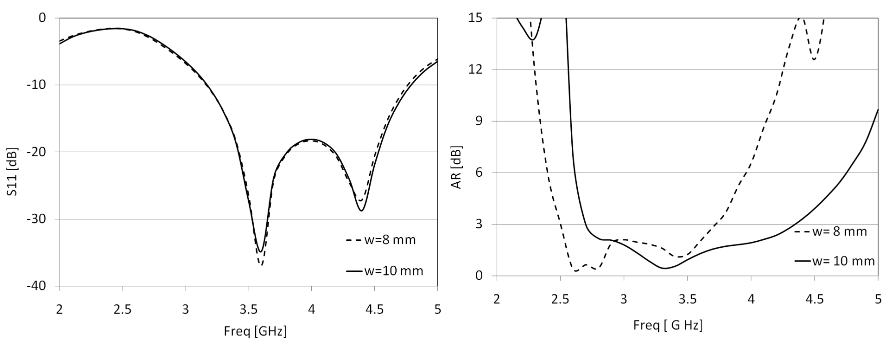


Figure 4. Electric field vector behaviour with oval stub in the slot at 3.5 GHz.



(a) S11 Characteristics (b) AR Characteristics (+y direction)

Figure 5. Effect of the width of the rectangular stub W.

enhance the bandwidth further and shown in Figure 4. Studying the electric field vector behaviour in the slot of the antenna reveals that, at the top right region in the slot, just next to the oval stub, the electric field vector has counter clockwise rotations.

In order to eliminate the counter clockwise rotations at this region, the oval stub is replaced with a rectangular stub, and the effect of which is explained henceforth.

3.3. Effect of the width (W) of the rectangular stub

The stub has a length (L) of 20 mm and is placed $S = 5$ mm from the centre of the antenna. The effect of the width (W) of the stub is optimized through parametric studies and is shown in Figure 5.

Variation in the width does not affect the S_{11} characteristics, and the bandwidth of 42.76% remains the same as in the case with oval stub. As the purpose of the stub is to cancel out undesired clockwise rotations and improve the AR bandwidth, and the variation is obvious on AR characteristics. A stub with a width of 10 mm completely eliminates the counter clockwise rotations in the slot, and broadband AR characteristics of 48% are obtained with the present design. The electric field behaviour at this instance is shown in Figure 6.

The magnetic current vector behaviour in the slot of the antenna, at 3.5 GHz for one complete cycle to explain circular polarization is shown in Figure 7. 0° to 300° in the figure are the polarization phase of the magnetic current vector at the respective instances. The electric field vector (Figure 6) and magnetic current vector (Figure 7) are perpendicular to each other, and both behaviours show clockwise rotations in the slot. This leads to the conclusion that the antenna generates circular polarization.

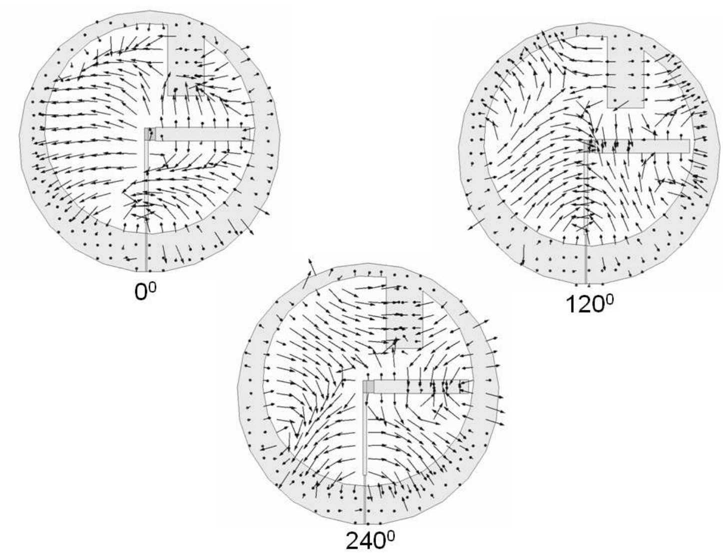


Figure 6. Electric field vector behaviour with rectangular stub in the slot at 3.5 GHz.

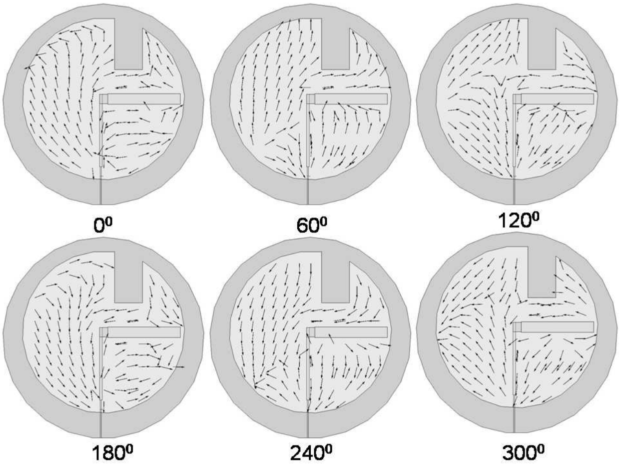
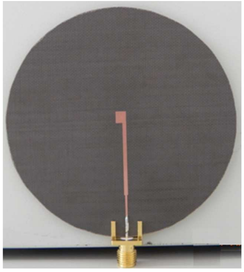
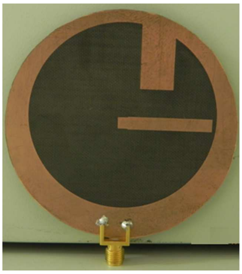


Figure 7. Magnetic current vector behaviour with rectangular stub in the slot at 3.5 GHz.



(a) Front view



(b) Back view

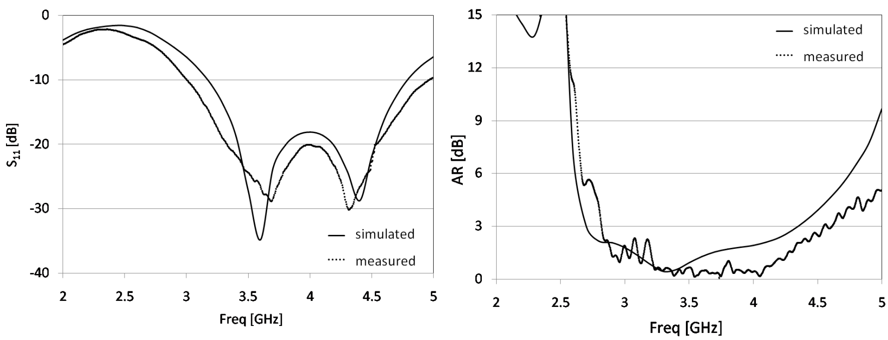
Figure 8. Fabricated antenna.

4. EXPERIMENTAL RESULTS

The circular slot antenna, with circular ground plane with the optimized parameters of $R_g = 7\,\text{mm}$, $C_z = 3.5\,\text{mm}$ and stub width $W = 10\,\text{mm}$, is fabricated on Arlon Diclad 522 substrate and shown in Figure 8. The measured results are presented herewith.

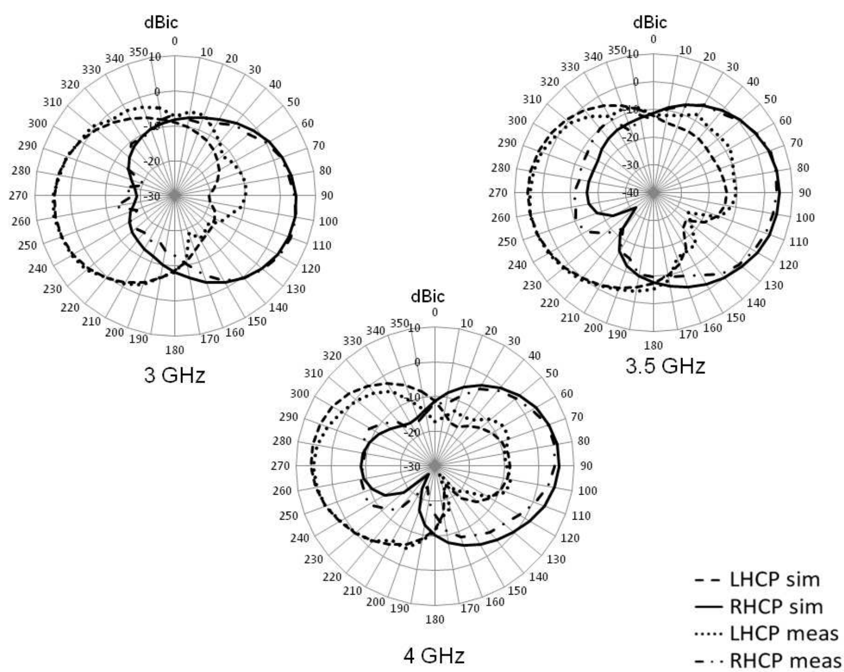
The measured S_{11} and AR characteristics are shown in Figure 9.

The S_{11} characteristics show slightly broadened characteristics from 3 GHz to 4.9 GHz of 48.1%. This may be because of the small gap at the joining point between the circular shaped antenna and the SMA connector. The AR characteristics are slightly shifted to the higher frequency end, but the bandwidth remains almost the same in both simulation and measurement. A simulated bandwidth of 48% is obtained from 2.69 GHz to 4.39 GHz where the measured results show a bandwidth of 48.31% from 2.81 GHz to 4.6 GHz. The overlapped bandwidth is 42.1% in measurement, which makes the antenna useful for many applications.

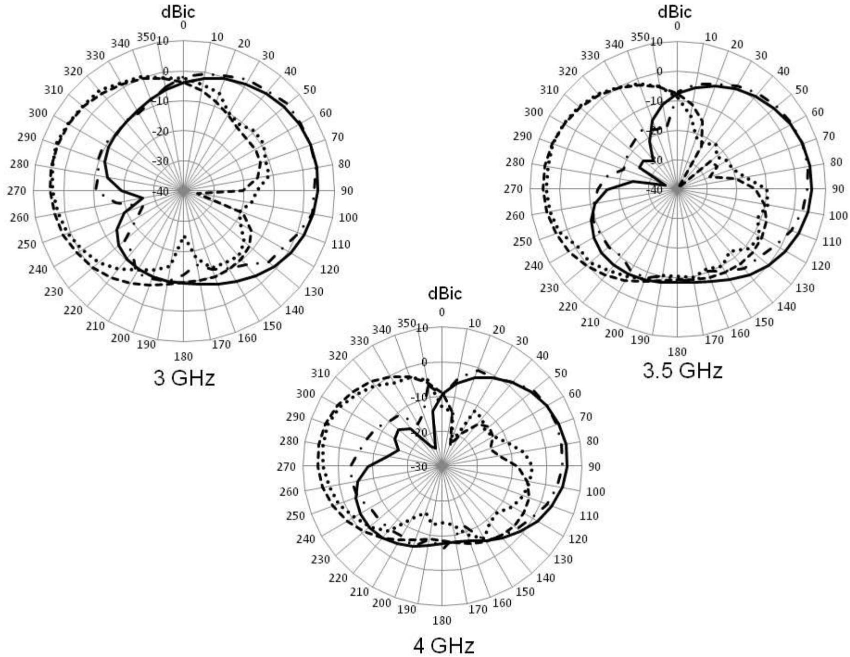


(a) S_{11} Characteristics (b) AR Characteristics (+y direction)

Figure 9. Characteristics of the antenna.



(a) x-y Plane



(b) y-z Plane

Figure 10. Radiation pattern.

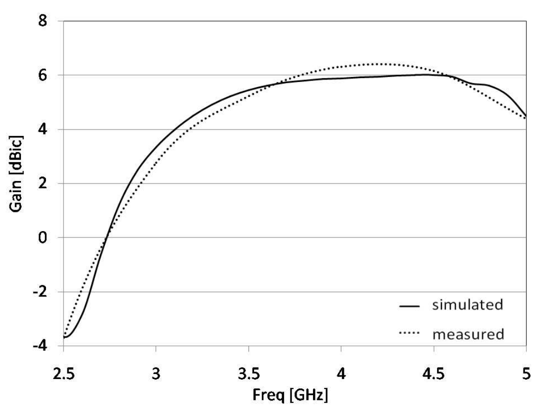


Figure 11. Gain characteristics ($+y$ direction).

This antenna also generates bidirectional radiation patterns, simultaneous LHCP and RHCP. The simulated and measured radiation pattern characteristics of the antenna in x-y and y-z planes for frequencies 3 GHz, 3.5 GHz and 4 GHz are shown in Figure 10. The frequencies in the AR band show good cross polarization discrimination (XPD) of more than 15 dB in simulation and measurement on a wide azimuth range from 50° to 150° at all the measured frequencies of 3, 3.5 and 4 GHz in x-y plane. A front to back (FB) ratio of more than 18 dB is achieved in 3 and 3.5 GHz and around 15 dB at 4 GHz. The radiation pattern in y-z plane also shows very good agreement with the measured results. A XPD of more than 15 dB is achieved along with a FB ratio of more than 18 dB for 3 GHz. A XPD of around 15 dB is achieved in the range of 30° to 100° with a FB ratio of 20 dB at 3.5 GHz and more than 15 dB in XPD from 20° to 90° with a FB ratio of 15 dB at 4 GHz.

The measured and simulated gain characteristics of the antenna shown in Figure 11 are in good agreement. A maximum gains of 6 dBic in simulation and 6.4 dBic in measurement are obtained.

5. CONCLUSION

A novel circularly polarized antenna with circular radiating aperture on a circular ground plane is presented in this paper. A rectangular stub is used for controlling the electric field vector behaviour in the slot and to enhance the AR bandwidth. A bandwidth of around 48% is achieved both in S_{11} and AR, along with an overlapped bandwidth of 42.1%. The presented circular slot antenna attains wideband circular polarization with only single stub in the slot compared to square slot antennas, where higher number of stubs are required to eliminate the undesired counter clockwise rotations. The presented antenna also shows better cross polarization discrimination on a wide azimuth range and maintains a maximum gain of 6 dBic on a wide band.

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